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Research Article

Multiple targets of the Global Biodiversity Framework must be addressed to manage invasive alien species in protected areas

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Abstract

The Kunming-Montreal Global Biodiversity Framework (GBF) sets out ambitious global targets to reduce biodiversity loss by 2030 and will determine the conservation agenda for the next decade. Invasive alien species are a major driver of biodiversity loss in terrestrial and marine ecosystems; and a key focus of the GBF is therefore to reduce their introduction by 50% through pathway management as well as eradicating or controlling established alien species in priority sites (Target 6). Protected areas are among the most important priority sites for the management of biological invasions. However, delivery of Target 6 for protected areas entails coordination with other GBF targets especially in relation to rapidly evolving pathways such as increasing international and domestic tourism (Target 15), progressive encroachment of urban areas (Target 12), development of intensive agriculture/aquaculture systems in buffer zones (Target 10), species rafting on marine plastic (Target 7), and growing risk from range-shifting species under climate change (Target 8). The management of established invasive alien species requires effective spatial planning (Target 1) to prioritise the limited human and financial resources available to manage biological invasions including recognising those protected areas facing the greatest immediate and future threat, identifying the species that pose the greatest risk to threatened species (Target 4) and/or Nature's Contributions to People (Target 11), and obtaining the necessary finance required to effectively control priority species (Target 19). The goal of expanding protected areas to cover 30% of land, water, and seas (Target 3) will need to avoid the inclusion of areas already harbouring invasive alien species. Addressing biological invasions must be an inclusive process (Target 22) undertaken over multiple years that involves the sharing of knowledge and data (Target 21). Decision-makers, protected area managers, researchers, and representative of local communities should all be involved in the regular prioritisation, implementation, and review of management activities. Consequently, the effective management of biological invasions to halt biodiversity loss by 2030 will not be realised by having an exclusive focus on achieving Target 6; it will also require that substantial progress is made with most GBF Targets. Elucidating the interconnectedness of different GBF Targets in relation to their direct or indirect role in the effective management of biological invasions reveals opportunities for a more integrated approach to biodiversity conservation. The inclusion of the multiple GBF targets in strategies to address invasive alien species is the step change needed to reduce the magnitude of this threat to biodiversity by 2030.

Key words: Aichi Targets, capability development, citizen science, IUCN, National Park, Nature Positive

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The case for more effective management of biological invasions in protected areas

The UN Convention on Biological Diversity (CBD) recently adopted the Kunming-Montreal Global Biodiversity Framework (GBF) that sets out 23 ambitious targets (Table 1) for transformative action to prevent further biodiversity loss by 2030 (CBD 2022). Each target is associated with a specific headline indicator against which progress can be measured. As a major global policy instrument, the GBF has already received considerable scrutiny, including the challenges of delivering specific targets (Hughes and Grumbine 2023; Li et al. 2023; Obura 2023). Undoubtedly Target 3 to protect 30% of the planet by 2030 through area-based conservation measures, that include marine and terrestrial protected areas, has attracted most interest (Gurney et al. 2023; Shen et al. 2023; Jago 2024; Riva et al. 2024). This target has placed the issue of protected areas at the heart of discussions regarding the GBF (Fitzsimons et al. 2025). Other targets that have received recent attention include Target 4 that aims to maintain genetic diversity within and among populations of all species (Hoban et al. 2023; Robuchon et al. 2023), Target 7 on reducing harmful pollution (Feckler et al. 2023; Mueller et al. 2023), Target 15 on decreasing the biodiversity-risks arising from business (Panwar 2023; Zhu et al. 2024), and Target 21 on ensuring equitable and effective biodiversity decision-making (Raymond et al. 2022; Jago 2024). In contrast, consideration of Target 6 on invasive alien species has primarily been in relation to quantifying the headline indicator rather than the challenge of delivering the target itself (McGeoch et al. 2023). Yet, it is evident that there is a progressive increase in the numbers, occupied areas, and impacts of invasive alien species in terrestrial and aquatic ecosystems (Roy et al. 2024). As a result, there is concern that even in well-resourced countries current strategies are insufficient to deliver Target 6 by 2030 (Garcia-Lozano et al. 2025).This unfortunate situation is symptomatic of limited progress to date on the domestic targets and actions agreed by most signatories to the GBF; it suggests that a major step change is needed to meet the 2030 deadline (Bell-James and Watson 2025). With many nations having limited resources to invest in biodiversity conservation, it seems sensible for actions to prioritise management of protected areas since they are already a well-established focus for conservation actions that often provide the core of national biodiversity management strategies and policies (UNEP-WCMC and IUCN 2024; Robinson et al. 2025).

Protected areas are legally designated to safeguard biodiversity and cultural resources and as the cornerstone of global nature conservation they are the primary focus of national and international efforts to mitigate the impacts of multiple drivers of biodiversity loss (Watson et al. 2014; Maxwell et al. 2020). As a result, biodiversity is usually significantly higher in protected areas than in the surrounding landscapes (Gray et al. 2016) and their legal status has meant they experience less environmental degradation than areas without such protection (Naughton-Treves et al. 2005; Gaston et al. 2008). Nevertheless, invasive alien species are among the primary threats to protected areas across multiple biomes worldwide including tropical and non-tropical forests, shrublands, savannahs and grasslands (Schulze et al. 2018). Understanding how best to manage biological invasions in protected areas is a critical priority for global conservation efforts (Roy et al. 2023). Such an approach must address invasive alien species within the protected areas themselves while also mitigating the threat of further biological invasions from the surrounding matrix and interactions with other drivers of biodiversity loss.

Table 1. Summary of the 23 global targets of the Kunming-Montreal Global Biodiversity Framework for action over the decade to 2030. The targets are clustered around three themes: A. Reducing threats to biodiversity (Target 1–8); B. Meeting people's needs through sustainable use and benefit-sharing (Targets 9 to 13); and C. Tools and solutions for implementation and mainstreaming (Targets 14 to 23). Summarised from information at https://www.cbd.int/gbf/targets.

1	Plan and manage all areas to reduce biodiversity loss.
2	Restore 30% of all degraded ecosystems.
3	Conserve 30% of land, waters, and seas.
4	Halt species extinction, protect genetic diversity, and manage human-wildlife conflicts.
5	Ensure sustainable, safe and legal harvesting and trade of wild species.
6	Reduce the introduction of invasive alien species by 50% and minimize their impact.
7	Reduce pollution to levels that are not harmful to biodiversity.
8	Minimize the impacts of climate change on biodiversity and build resilience.
9	Manage wild species sustainably to benefit people.
10	Enhance biodiversity and sustainability in agriculture, aquaculture, fisheries, forestry.
11	Restore, maintain, and enhance nature's contributions to people.
12	Enhance green spaces and urban planning for human well-being and biodiversity.
13	Increase the sharing of benefits from genetic resources, digital sequence information and traditional knowledge.
14	Integrate biodiversity in decision-making at every level.
15	Businesses assess, disclose and reduce biodiversity-related risks & negative impacts.
16	Enable sustainable consumption choices to reduce waste and overconsumption.
17	Strengthen biosafety and distribute the benefits of biotechnology.
18	Reduce harmful incentives by at least $500 billion per year and scale up positive incentives for biodiversity.
19	Mobilize $200 billion per year for biodiversity from all sources, including $30 billion through international finance.
20	Strengthen capacity-building, technology transfer, and scientific and technical cooperation for biodiversity.
21	Ensure that knowledge is available and accessible to guide biodiversity action.
22	Ensure participation in decision-making and access to justice and information related to biodiversity for all.
23	Ensure gender equality and a gender-responsive approach for biodiversity action.

Concerns regarding the negative consequences of biological invasions in protected areas have a long history (Brockie et al. 1988; Usher 1988; Foxcroft et al. 2017) and this threat has become progressively worse over the last three decades despite the implementation of many long-term management programmes (Shackleton et al. 2020b). The total economic cost of invasive alien species in protected areas between 1975 and 2020 has been estimated to be more than US$ 20 billion, much higher than comparable non-protected areas (Moodley et al. 2022). However, not all costs can be put in monetary terms and invasive alien species have been identified as posing a threat to more than half of all UNESCO World Heritage Sites (Shackleton et al. 2020a). In contrast to World Heritage Sites, more than 50% of global protected areas are less than <100 ha and these are generally more vulnerable to invasion than larger reserves (Volenec and Dobson 2020). Furthermore, invasive alien species are often present in landscapes surrounding protected areas and thus the pressure from biological invasions is a continuing issue for protected area management, even where such areas are relatively free of invasive alien species (Liu et al. 2020; Holenstein et al. 2021).

Invasive alien species are only one of multiple pressures acting on biodiversity in protected areas. Managers need to balance their resources to not only address biological invasions but also deal with other threats such as encroachment by urban and agricultural land uses, diffuse and point-source pollution, natural resource exploitation such as logging and mining, anthropogenic fire, and climate change. So how important is the relative threat from biological invasions to protected areas? In the only systematic comparison to date, Cadotte et al. (2024) reviewed information on 230 UNESCO World Heritage Sites and found that invasive alien species ranked as one of the most frequently identified threats posing a greater degree of concern than other threats to biodiversity. Moreover, land-use change, exploitation of natural resources and climate change can exacerbate the threats from invasive alien species though the significance of such interactions remains poorly understood (Hulme 2022). Given that management targeting invasive alien species has been shown to be one of the most effective interventions having a positive effect on biodiversity (Langhammer et al. 2024), future proposals to bring the loss of biodiversity close to zero by 2030 (Target 1) should prioritise the management of threats posed by biological invasions.

Target 6 of the GBF aims to reduce the introduction of invasive alien species by 50% and minimise their impact by 2030 (CBD 2022). This clearly requires the identification and management of the introduction pathways of invasive alien species and the control of established species at priority sites. However, the scale of these interventions, whether at a national, regional or local scale, is unclear. Preventing the introduction of alien species across international borders is certainly important (Hulme 2021; Roy et al. 2024), but there is often a significant legacy of invasive alien species already established in most countries that have the potential to spread more widely and impact sites of high biodiversity value (Liu et al. 2020; Holenstein et al. 2021). Addressing this latter threat requires Target 6 to also focus on preventing the introduction and establishment of invasive alien species as well as managing current invasions in priority sites such as protected areas. For over twenty years, the CBD has recognised that member states should take measures to control risks associated with invasive alien species in protected areas (CBD 2004). In addition, many of the other GBF Targets that address area-based conservation are also relevant to managing invasive alien species whether through restoring degraded lands (Target 2), expanding the coverage of protected areas (Target 3), minimising the effects of climate change (Target 8), enhancing sustainability of primary industries (Target 10) or ensuring businesses reduce biodiversity related risks (Target 15).

To date, there has been no effort to understand the interplay of different GBF Targets in relation to minimising the threat of biological invasions. Here, we describe how multiple GBF targets are important to the effective prevention and management of biological invasions, especially in priority sites such as protected areas. By demonstrating the interconnectedness of several key GBF Targets in relation to their direct or indirect role in the effective management of biological invasions, we illustrate the opportunities for a more integrated approach to biodiversity conservation using examples drawn from both terrestrial and aquatic protected areas around the world (Fig. 1). We examine the relevance of each of the 23 GBF Targets to the management of biological invasions by first exploring the role of broad scale overarching targets before clarifying the interplay between specific targets and invasive alien species management through examples relating to data accessibility, spatial planning, and interventions to limit introduction pathways.

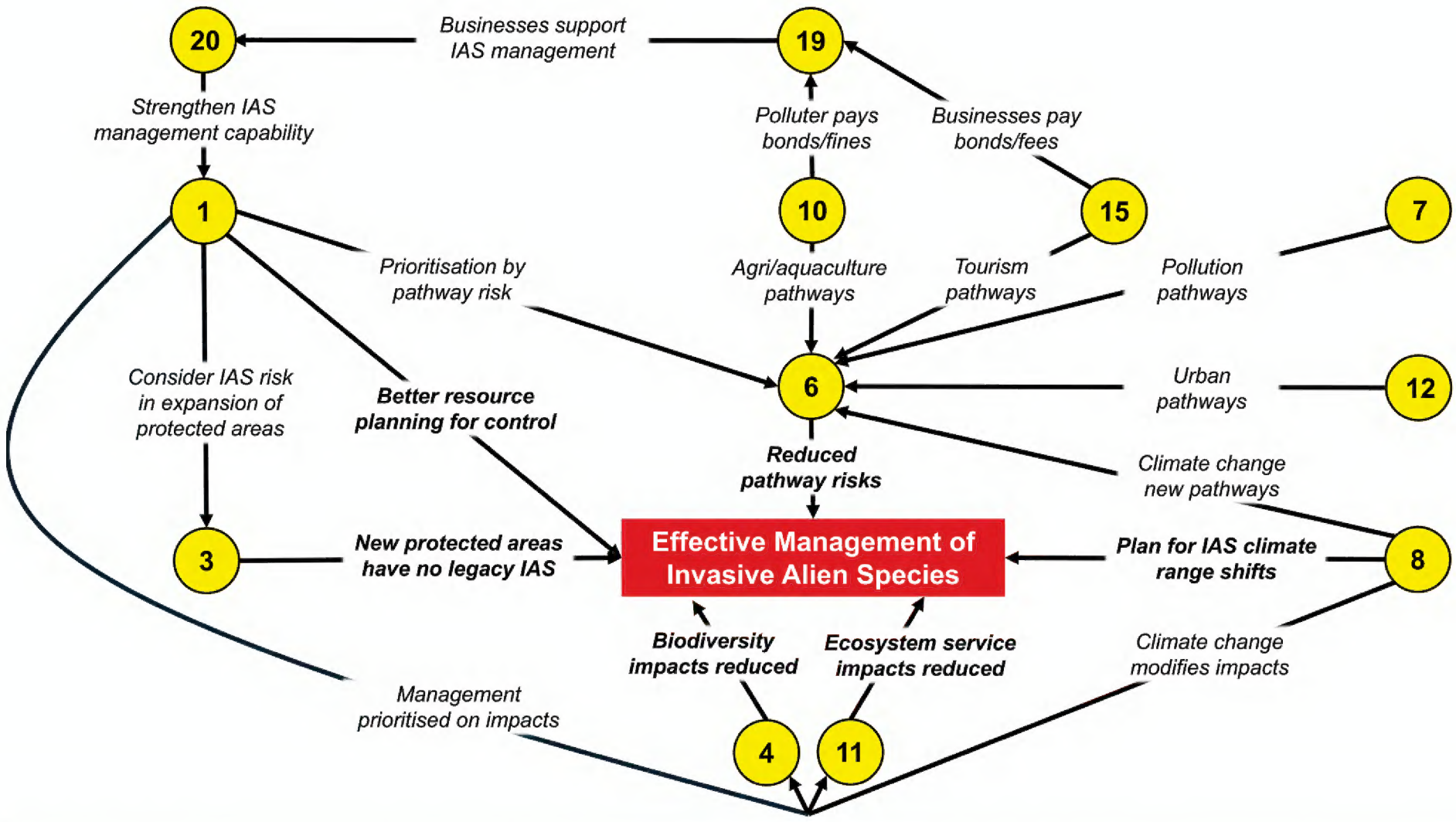

Figure 1. Schematic representation to illustrate how 12 targets of the Global Biodiversity Framework (GBF) interlink in relation to the management of invasive alien species (IAS) in protected areas. Numbers in circles identify the GBF Target number. Arrows represent processes linking the different targets or directly acting on invasive alien species (the central box). Ultimately all targets affect either directly or indirectly the management of invasive alien species. Target 6 is a major hub, receiving inputs from Targets 1, 7, 8, 10, 12 and 15 highlighting the complexity of pathway management in the face of urban expansion, agricultural encroachment, tourism, pollution, and climate change. In contrast, Target 1, influences multiple targets through spatial planning and effective management processes that prioritise actions in protected areas in relation to pathway risks (Target 6), impacts on biodiversity (Target 4) and ecosystem services (Target 11) especially where modified by climate change (Target 8) as well as assessing opportunities for the expansion of protected areas (Target 3) that account for any risk of legacy invasive alien species. Achieving Target 1 will require a step-change in capacity and capability (Target 20) among decision makers and managers that may be partially funded through taxes and fees from businesses that either pose a threat to or benefit from biodiversity conservation (Target 19). The schematic is illustrative rather than exhaustive, and each arrow is associated with a summary statement describing an example of an action that might occur. Six key actions that feed directly into improved invasive alien species management are highlighted in bold: reducing pathways risk, planning for range-shifting alien species, mitigating impacts on biodiversity and ecosystem services, ensuring new protected areas have no legacy invasive alien species, and resourcing managers sufficiently that they can take effective management actions.

Overarching GBF Targets and management of biological invasions in protected areas

The 23 GBF Targets for 2030 aim to reduce threats to biodiversity, meet people's needs through benefit sharing and provide tools for implementation of programmes designed to reverse the global decline of the integrity of ecosystems and their constituent species (Table 1). Thus, all targets could be perceived as relevant to area-based conservation and, logically, also to the management of biological invasions. For example, some targets are sufficiently generic that they should be viewed as overarching principles for all conservation actions. These include targets addressing equity issues including the sharing of benefits from genetic resources, digital sequence information and traditional knowledge (Target 13), ensuring equitable access to knowledge (Target 21), inclusive participation in decision-making (Target 22) and gender responsive actions (Target 23). Invasive alien species add to the marginalization and inequity, including gender-differentiated impacts, of

indigenous peoples, ethnic minorities, migrants, and poor rural and urban communities that are often disproportionately impacted by biological invasions (Roy et al. 2023). Similarly, the goals to integrate biodiversity in decision making at every level (Target 14) as well as to reduce harmful incentives by at least $500 billion per year and scale up positive incentives for biodiversity (Target 18) sit at a much higher level of governance than simply oversight of a protected area network. This again highlights that the threat posed by biological invasions must be incorporated into policies, regulations, planning and development processes and environmental impact assessments across all levels of government (Roy et al. 2024).

Several GBF Targets sit outside the direct ambit of protected areas such as measures to improve the handling of biotechnology (Target 17) and encouraging sustainable consumption (Target 16). It is, however, possible to imagine downstream implications of these targets not being met subsequently impacting protected areas. Two targets suffer from ambiguity in that they refer to sustainable harvest (Target 5) or management (Target 9) of wild species and these are defined by the CBD as "organisms captive or living in the wild that have not been subject to breeding to alter them from their native state" (Tian et al. 2023). While invasive alien species could be considered as wild species under such a broad definition, and certainly are the subject of harvesting by local communities (Seaman et al. 2024), Fig. 2a), the benefits to human livelihoods do not always outweigh the environmental costs, nor are they always equitably shared, and can lead to perverse outcomes that encourage further biological invasions (Shackleton et al. 2019; Carneiro et al. 2024). Finally, an assumption is that current and future protected areas will not include degraded ecosystems (Dudley 2008) and that the target to restore 30% of degraded ecosystems by 2030 will focus on areas outside of the current protected area network (Target 2). Nevertheless, it makes sense if ecosystems close to or adjoining existing protected areas were prioritised for restoration since such actions should make buffer zones more effective barriers to biological invasions through the removal of alien species from restored areas as well as increasing the resistance of boundary ecosystems to future invasions (Foxcroft et al. 2011).

Accessibility of baseline data on invasive alien species to measure future progress

At the heart of any strategy to prevent or manage biological invasions (Target 6) is the need for information on which alien species are currently present in a protected area, and the species that are absent but have a high probability of becoming introduced into the protected area. Greater knowledge is required regarding the actual or potential impacts of both these categories of alien species on biodiversity and ecosystem services. This information is critical for planning and managing all areas to reduce biodiversity loss (Target 1) and will be needed to ensure better resource planning for any management programmes targeting biological invasions (Fig. 1). Similarly, the goal of conserving 30% of land, inland waters, and seas (Target 3) will require an expansion of the protected area network in many countries and knowledge of alien species in areas proposed for future protection will be essential to establish a sound baseline for future monitoring and to avoid including a legacy of past invasions that will be a burden on management resources for the foreseeable future (Fig. 2a).

It is important that the best available data, information and knowledge regarding invasive alien species are accessible to decision makers and practitioners to

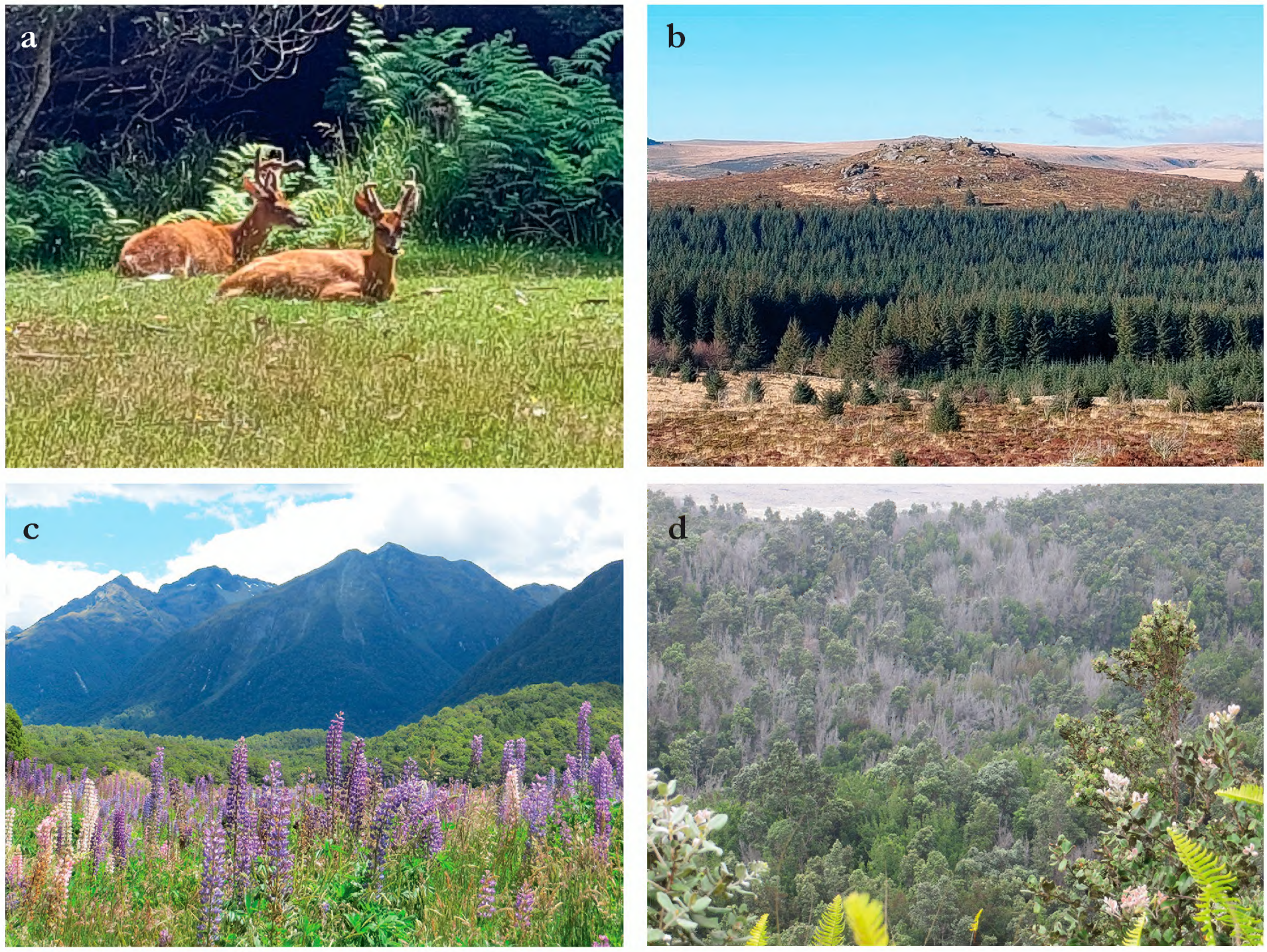

Figure 2. Four examples of invasive alien species in protected areas that illustrate the challenges of management of biological invasions in relation to pathways, legacies, and conflicts that need to be considered in the delivery of the Global Biodiversity Framework Targets: **a** White tailed deer (*Odocoileus virginianus*) in Rakiura National Park, New Zealand. Deer were present prior to the gazetting of the park in 1987 but cause conflict since they are favoured by hunters but harm biodiversity; **b** Russel lupin (*Lupinus polyphyllus*) in Arthurs Pass National Park, New Zealand. This nitrogen fixing species reduces native plant diversity but is popular with tourists who don't want it controlled and spread the seed; **c** Sitka spruce (*Picea sitchensis*) plantations in Dartmoor National Park, United Kingdom. The conifer spreads from plantations with major transformation of the heathland ecosystem; and **d** Rapid Ohia Death on *Metrosideros* spp in Hawai'i Volcanoes National Park, USA. The fungal disease is expected to become widespread because of climate change and more extreme winds that spread the spores. Photo credits Philip Hulme.

guide effective, integrated and participatory management of biological invasions (Target 21). However, unlike many other threats to protected areas, such as agricultural encroachment, logging or fragmentation, the pressure from invasive alien species is not easily assessed using remote sensing but requires on-the-ground data (Hulme 2018). The ideal would be to collect standardised data on the richness and distribution of alien species derived from systematic surveys that provide comparable data across protected areas irrespective of their size, ecosystem or topography. Such data can provide a baseline against which progress with management plans can be assessed (Hui et al. 2011). Unfortunately, such comprehensive data encompassing multiple protected areas in a region are rarely available, even for plants that are often the most easily assessed component of alien biota (Pysek et al. 2003).

Instead, the assessment of invasive alien threats in protected areas is often based on data derived from protected area management plans (Figueiredo et al. 2024; Shrestha et al. 2025). Yet, the quality of information derived from protected area management

plans has been shown to be quite variable as a result of limitations in funding, staffing, suitable equipment and monitoring capability (Ervin 2003; Gaston et al. 2008; Hoffmann 2022; van Wilgen et al. 2025). Such data can often be supplemented with checklists from published literature, although the coverage of such information can be patchy both in space and time making it more suited for establishing baselines than monitoring progress with GBF Targets (Cantú-Salazar and Gaston 2013; Gallardo and Capdevila-Argüelles 2024; Fernández Winzer et al. 2025).

An additional source of complementary data on the distribution of invasive alien species both within and outside of protected areas can be derived from citizen science platforms such as iNaturalist (Young et al. 2021). Citizen science is an important means to strengthen communication, awareness-raising, monitoring, and knowledge management (including traditional knowledge) regarding biological invasions (Target 21). However, it is well recognised that citizen science data are prone to strong biases often being proximate to roads or other trails, close to urban areas, and often selective in the ecosystems or taxa surveyed (Geurts et al. 2023; Pocock et al. 2024). Such biases do mean a higher likelihood of picking up alien species which could be seen as an advantage but may also provide a biased view of the level of invasion since data will be representative of disturbed environments rather than more pristine ecosystems where risks to biodiversity from biological invasions might be greatest (Dimson et al. 2023).

Spatial planning requires data on invasion pathways, impacts, and management costs

While a sound baseline describing the level of invasion by different alien taxa in protected areas is essential for subsequent monitoring and reporting against GBF Target 3 and Target 6, it is also critical for biodiversity inclusive spatial planning and effective management processes (Target 1). Ideally, spatial planning to combat biological invasions should be an inclusive process undertaken over multiple years involving decision-makers, protected area managers, researchers, and representative of local communities in the regular prioritisation, implementation, and review of management activities (Rouget et al. 2024). For biological invasions there are at least three aspects of spatial planning that need to be considered when prioritising the limited resources available to manage invasive alien species: a) what protected areas are most at risk from current or future biological invasions, b) within these areas which species pose the greatest threat to biodiversity and thus should be prioritised for management, and c) how much would it cost to effectively control the species.

Prioritising protected areas

By combining data on the occurrence of invasive alien species within and around protected areas with knowledge of existing introduction pathways it may be possible to identify which protected areas should be prioritized for prevention and which should be prioritized for control (Brancatelli and Zalba 2018; Silva et al. 2024). Risk assessment tools can then be applied to candidate species to identify the likelihood that they may become introduced into a protected area (Fig. 1). Such prioritisation has been based on the area of suitable habitat under current or future climate scenarios (D'Amen and Azzurro 2020). However, also including knowledge of the most likely pathways for species introduction (Silva et al. 2024; Castro et al. 2025), would

better inform management priorities. Such risk assessment tools will not only be important in the delivery of Target 6 but also for any spatial planning of resources to deliver conservation outcomes (Target 1) and strategies to expand the coverage of protected areas while avoiding the inclusion of invaded ecosystems (Target 3).

Ranking invasive alien species for management

Prioritising the allocation of limited resources available for management to target most effectively the alien species already established in a protected area is key to delivering the greatest conservation benefits at the lowest cost. However, there is currently limited guidance on appropriate prioritisation schemes to support invasive alien species management (Forner et al. 2022). Existing prioritisation schemes often use attributes such as a species' tendency to invade sensitive habitats, its frequency of occurrence and its propensity to spread in the protected area to identify which species to target as a priority (Ziller et al. 2020; Finley et al. 2023). While these go some way to assisting management decisions, often missing from such assessments is knowledge of the potential impact of alien species and the ease with which they can be controlled (Fig. 1). Unfortunately, this information is not available for many alien species and estimates of impacts drawn from global databases may not reflect the actual outcomes for species or ecosystems in a specific protected area (Gallardo and Capdevila-Argüelles 2024). Similarly, management options that might be effective in one part of the world may not be appropriate in another, leaving managers to devise their own control methods through trial and error. For all management interventions it is essential to assess their potential unintended effects on biodiversity that may impact on the delivery of other GBF Targets such as pollution (Target 7) from pesticides, herbicides and fungicides (Feckler et al. 2023) or the potential biosafety risks (Target 17) of using genomic technologies to manage biological invasions (McGaughran et al. 2024).

Assessing the cost of management

Effective management of invasive alien species requires a clear understanding of the resources needed to adequately complete the job. Costs of management are routinely underestimated (van Wilgen et al. 2025). Management tools can be developed that establish standards for alien species management that capture the size of the problem, the methods required, and the feasibility of successfully dealing with the species that together allow for accurate financial planning of any interventions undertaken (Cheney et al. 2019, 2020) However, the effectiveness of any management intervention should not simply be based on the outputs in terms of number of animals culled or area cleared of weeds, but on outcomes in relation to the subsequent impact on biodiversity and ecosystem services (van Wilgen et al. 2025). A comprehensive review of the consequences of biological invasions in protected areas highlights that many invasive alien species have led to major declines in the population abundance of native species, in some cases leading to extinctions and structural changes to ecosystems (Carneiro et al. 2025). It is therefore essential to develop objective indicators to monitor progress with Target 6 (Fernández Winzer et al. 2025) and to link these to clear outcomes relating to halting species extinction and protecting threatened species (Target 4) and the enhancing of Nature's Contribution to People (Target 11).

An understanding of future introduction pathways of invasive alien species, the biodiversity risks posed by existing species within protected areas, accurate estimates

of the costs of management and reviews of management effectiveness are all elements of a protected area management toolkit that are essential to deliver Target 6 but also by implication Target 1, 4, and 11 (Fig. 1). Deployment of such a toolkit at a global scale will require significant investment in capacity-building to bring the skills of protected area managers up to a level where they can effectively address biological invasions and meet GBF Targets. This will also need stronger international cooperation and technology transfer to meet the needs of effective implementation (Target 20). Investment in capacity development to address biological invasions must be a priority for any resources leveraged from international finance (Target 19).

Uncertainty in invasion pathways due to changes in economy, land-use, and climate

The identification and management of the introduction pathways of invasive alien species is central to achieving Target 6. Predicting likely pathways of introduction into protected areas is challenging. Rather than direct assessments of propagule pressure, proxies such as distance to nearest urban centre or road density for terrestrial systems (Silva et al. 2024) or distance to nearest harbour or vessel route density for marine systems (Iacarella et al. 2020; Castro et al. 2025) are often used. While possibly adequate to assist in prioritisation of protected areas for management actions, such assessments need to acknowledge the inherent uncertainty in any predictions of risk. Furthermore, such assessments capture the status quo of what might be the most important contemporary pathways they seldom extend the risk assessments into the future. Introduction pathways are highly dynamic and rapidly changing (Hulme 2015) requiring that any management plans to prevent future introduction need to be forward looking. For example, an emerging risk for marine protected areas is plastic pollution (Bonanno 2022). While the GBF Target 7 aims to reduce pollution to levels that are not harmful to biodiversity, its focus is entirely on direct impacts of pollutants and it does not consider that marine plastics can be a novel pathway for the introduction of alien species (García-Gómez et al. 2021).

There are least four rapidly changing pathways through which alien species will be introduced into protected areas in the future that need to be considered by managers and spatial planners that highlight the linkages between Target 6, 8, 10, 12, 15 and 19 (Fig. 1): a) increasing international and domestic tourism, b) progressive encroachment by urban areas in buffer zones, c) development of intensive agriculture/aquaculture systems in buffer zones and d) climate change.

Tourism

Except for some strict nature or scientific reserves most protected areas are accessible to the public (Dudley 2008). Tourism in protected areas is a major component of the global tourism industry and can promote a conservation mindset among visitors potentially contributing positively to nature preservation while also providing much needed employment and income to regions with few other economic alternatives (Leung et al. 2018). Balancing the benefits of tourism in terms of regional income and biodiversity awareness against the costs arising from harmful impacts of associated tourism infrastructure (e.g., roads, accommodation) as well as the threat from both deliberate and inadvertent introduction (Fig. 2b) of invasive alien pests, weeds, and pathogens remains an unresolved challenge in many protected

areas. Key to resolving such a challenge is an understanding of the risk tourism might pose as a pathway for alien species introductions. Hulme (2024) illustrates how this might be achieved using national surveys of international tourists in New Zealand to capture travel itineraries and activities of different nationalities with the analysis showing that visitors from Western Europe pose a higher risk than other nationalities. These findings caution against treating all visitors to protected areas as posing a similar risk, and might explain why the total number of visitors to protected areas does not always adequately explain patterns of biological invasion (Gallardo and Capdevila-Argüelles 2024). Given the important role that protected areas play in sustaining the global tourism industry it would seem to be a business sector that should be engaged to reduce its biodiversity related risks and negative impacts, especially in relation to the introduction of invasive alien species (Target 15). Thus, tourism companies should be required to regularly monitor, assess and transparently disclose their risks and impacts relating to biological invasions and provide information to tourists regarding the risk of introducing invasive alien species. Furthermore, it should be possible to ensure a proportion of the financial benefits arising from tourism is reinvested in protected areas through realistic pricing of tourist operator concessions and visitor fees (Hulme 2024). This approach would also contribute to increasing the level of financial resources available to implement biodiversity strategies and action plans (Target 19).

Urbanisation

Many protected areas have elements of built environments near their boundaries. At a global scale, built-up areas within a 10km buffer zone around protected areas have increased dramatically between 1975 and 2014, particularly around smaller, coastal, or more recently established protected areas (de la Fuente et al. 2020). Urbanisation in buffer zones brings many potential problems to the conservation of protected areas not least of which is the fact that urban areas present an important source of invasive alien species that spread into the surrounding landscape (Padayachee et al. 2017; Boscutti et al. 2022). For this reason, the human population density in a 10km buffer around protected areas was found to be a good predictor of invasion threat in terrestrial protected areas of Brazil (Silva et al. 2024). Since urban areas near to protected areas represent a pathway for biological invasions, it is important GBF Target 12 that aims to ensure biodiversity-inclusive urban planning also considers the invasion risks arising from urbanisation by promoting the use of native rather than alien species in urban planting and prohibiting the sale of high-risk alien pets in settlements within 10km of a protected area.

Forestry and aquaculture

While urbanisation in the buffer zones of protected areas may be a source of future biological invasions, agricultural land-use can also pose a risk if not carefully managed. In particular, plantation forestry using alien species can facilitate the spread of alien conifers into neighbouring protected areas (McConnachie et al. 2015), Fig. 2c). In marine ecosystems, aquaculture facilities proximate to protected areas can also result in the spread of invasive alien species (Giakoumi and Pey 2017) and these facilities were found to be a good predictor of invasion threat in marine protected areas of Brazil (Silva et al. 2024). While the GBF has a goal addressing

the need for sustainable agriculture, aquaculture, and forestry to enhance biodiversity (Target 10), it needs to explicitly consider the role these sectors play in both the introduction and spread of invasive alien species, especially with reference to neighbouring protected areas. Guidelines for sustainable forestry production already exist and recommend that commercial plantation forests using alien tree species should not be planted within 10km of a protected area (Brundu et al. 2020). Similarly, proposals exist to ensure aquaculture is developed in a synergistic manner with marine protected areas with an emphasis of using native rather than alien species (Le Gouvello et al. 2017). Applying a polluter pays fine or bond for those forestry or aquaculture businesses that use alien species and have not implemented sufficient safeguards to prevent escape could be an additional source of income to support management of invasive alien species within protected areas, particularly surveillance that would contribute to biodiversity conservation (Target 19).

Climate change

Climate change has long been recognised as an environmental driver capable of exacerbating biological invasions by increasing the geographic distribution, population abundance and environmental impact of invasive alien species (Finch et al. 2021). Several studies point to an increased risk of biological invasions into protected areas as the climate warms (Kleinbauer et al. 2010; Vicente et al. 2013; Dai et al. 2018). Climate change will also alter the character and magnitude of different introduction pathways, thereby placing increasing pressure on the management of protected areas. Extreme events, such as floods and storms, will not only make ecosystems more vulnerable to invasion but facilitate the long-distance dispersal of alien species into protected areas (Fig. 2d) and in marine ecosystems the loss of polar sea ice will allow more extensive vessel movement that can introduce alien species (Goldsmit et al. 2020; Lieurance et al. 2025). Increased warming may allow alien species to become established in protected areas that were previously climatically unsuitable such as in alpine and polar areas (Gallardo and Capdevila-Argüelles 2024). Furthermore, warming may destabilise ecosystems resulting in a loss of native species and an increased risk of invasion (Hansen et al. 2014; D'Amen and Azzurro 2020). While the GBF has a goal to minimise the impacts of climate change on biodiversity (Target 8), this is a major challenge in terms of the management of invasive alien species in protected areas since it requires an understanding of the vulnerability of the ecosystem to climate change, the responsiveness of alien species to an alternate climate regime, and the risk of range-shifts by new alien species (Lieurance et al. 2025). Climate modelling tools can be useful in this regard for understanding changes in alien species risks (Gallardo and Capdevila-Argüelles 2024; Kumschick et al. 2025) but should also be extended to consider those native species already threatened by invasive alien species to assess how such impacts may change in the future.

Hitting all the right targets: towards a holistic view of achieving the GBF

A cynic might argue that the CBD is somewhat obsessed with establishing ambitious global targets that are rarely if ever met. Two decades ago the CBD set governments the single goal to achieve a significant reduction in the rate of biodiversity loss by 2010, but when this was not met, the CBD proposed a set of 20 specific targets

to be met by 2020, known as the Aichi Targets (CBD 2020). The Aichi Targets were not especially successful and most countries failed to make progress with the targets or indeed actually moved away from them (Buchanan et al. 2020). The criticism of the GBF so soon after its launch in 2022 (Raymond et al. 2022; Hughes and Grumbine 2023; Li et al. 2023; Obura 2023; Zhu et al. 2024) suggests that there is a significant risk that it will simply repeat the muted achievements of the Aichi Targets. Part of the problem is, of course, that conserving biodiversity costs money and many of the regions that contain large areas of untransformed ecosystems do not have the resources, capability, or robust governance structures to deliver the GBF.

Superficially, progress towards achieving Target 6 at a global scale should be possible since Aichi Target 9 addressing alien invasive species was partially met and shares many similarities to Target 6 given that its goal was that by 2020, "invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated and measures are in place to manage pathways to prevent their introduction and establishment" (CBD 2020). However, it should be clear from the previous section that Target 6 is a much more complex goal than has been appreciated so far, especially for protected areas (Fig. 1). Indeed, Target 6 cannot be effectively addressed without consideration of multiple other targets. If each target is implemented in isolation and in the absence of an understanding of their roles in biological invasions, then it is hard to see Target 6 being achieved successfully at a global scale.

A limitation of Target 6 is that the spatial scale at which it needs to be interpreted is unclear. Introduction pathways can be managed to some extent through international border biosecurity controls that involve the inspection of imported commodities, screening of incoming overseas travellers, and associated transport vectors (Hulme 2015). However, many invasive alien species that threaten biodiversity may already be established in a country and thus a priority would be to prevent further spread. Thus, a stronger focus on delivering Target 6 specifically for protected areas may indeed be more achievable since it would focus actions on specific biodiversity hotspots and clearly identify the most relevant stakeholders and decision-makers involved at a national scale. In addition, a focus on actions targeting a specific area of land, freshwater, or ocean will likely be more appealing to businesses who wish to invest in conservation through initiatives such as Nature Positive (Milner-Gulland 2022), since they would be able to have a tangible indication of the outcome of their investment that could be disseminated to their shareholders and staff. However, the management of protected areas should take a much more holistic perspective to achieving the GBF Targets and it is probably time for the CBD to revise its programme of work on protected areas (CBD 2004) to better capture the network of linkages among different targets. At the same time, IUCN should revisit its own guidelines on the management of protected areas in particular in relation to sustainable tourism (Leung et al. 2018), urbanisation (Trzyna 2014), climate change (Gross et al. 2016) and marine protected areas (Lewis et al. 2017) so that they much more explicitly consider the current and future impacts of biological invasions and their management.

Given the potential scale of biological invasions some consideration should be made regarding different tactics for implementing Targets, 1, 3 and 6 depending on the management categories of protected areas, particularly in relation to the degree to which human activity is permitted within their boundaries (Targets 5, 9 and 11). For example, the IUCN categorisation is a global standard that distinguishes protected areas on their level of protection from the strictest that have the least human access (Ia strict nature reserve and Ib wilderness area) to those where the distinct

character is in part shaped by the interaction between nature and humans (VII protected areas with sustainable use of natural resources) such that management accommodates human impacts in support of cultural or scenic values as well as traditional harvests (Dudley 2008). While it may be expected that biological invasions will increase as the management criteria become more accommodating of human activity, this does not appear to be borne out by the limited data available to date (Liu et al. 2020; Figueiredo et al. 2024). There is clearly scope for greater understanding of how protected areas under different IUCN management categories differ in their vulnerability to invasive alien species and the role that conservation actions play in preventing biological invasions. Similarly, given the relative dearth of research on biological invasions in protected areas (Hulme et al. 2014), more studies should explore the impacts of invasive alien species, especially with reference to IUCN protection categories. Such information, combined with systematic inventories of invasive alien species in protected areas would be the basis for any prioritisation exercise.

Conclusions

The GBF Target 6 seeks to eliminate, minimize, reduce and or mitigate the impacts of invasive alien species on biodiversity and ecosystem services by identifying and managing pathways of the introduction of alien species, preventing the introduction and establishment of priority invasive alien species, reducing the rates of introduction and establishment of other known or potential invasive alien species by at least 50 per cent by 2030, and eradicating or controlling invasive alien species, especially in priority sites, such as islands (www.cbd.int/gbf/targets). This is undoubtedly an ambitious task that will stretch the capacity and capability of decision-makers, protected area managers, local and indigenous communities, as well as researchers. Achieving of Target 6 depends also upon delivering on almost all the other GBF Targets, yet in most cases these targets do not explicitly consider invasive alien species. The interplay among different GBF Targets as conceptualised in Fig. 1 highlights the complex linkages and emphasises the need to develop a more integrated approach. It is quite clear that the different targets should not be viewed in isolation, and that in the case of biological invasions multiple targets need to be considered to reduce the impact of invasive alien species on biodiversity and ecosystem services. This is especially the case for targets addressing area-based conservation measures since invasive alien species are known to have a major role in the loss of biodiversity in protected areas.

The interconnectedness among the GBF targets lead to six key actions that feed directly into improved invasive alien species management: reducing pathways risk, planning for range-shifting alien species, mitigating impacts on biodiversity and ecosystem services, ensuring new protected areas have no legacy invasive alien species, and resourcing managers sufficiently that they can take effective management actions (Fig. 1). These outcomes highlight that protected area managers cannot achieve Target 6 without the closer involvement of a wider range of stakeholders across a hierarchy of scales. For example, at a national scale, government policy-makers will need to ensure any expansion of the protected area network mitigates against any legacy invasive species, regional planners will need to consider the risk of invasions when designing urban green spaces and infrastructure corridors, while the aquaculture, agriculture, horticulture and forestry sectors will need to prevent the local feralization of alien crops and livestock. The management of biological invasions illustrates why a more holistic approach to the GBF Targets is essential.

Unfortunately, this important perspective is not yet sufficiently appreciated by policymakers striving to achieve Target 6 by 2030 (CBD 2024). The inclusion of the multiple GBF targets in strategies to address invasive alien species is the step change needed to reduce the magnitude of this threat to biodiversity by 2030.

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Data availability

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